HIPLM User Manual

A general user guide v.1.0

By
Dominic Carrier
&
Dominic Lepage

Last updated: 15th September 2012

Table of contents

HIPLM User Manual

Introduction

General introduction to the hyperspectral system

The hyperspectral photoluminescence mapper (HIPLM) is a specially modified microscope system. The instrument captures 2D images of a sample (XY image) spectrally dispersed in a 3rd dimension as a function of the collected light's energy (E). The final images produced by the system are stored within a cube of data, generating a "hyperspectral" cube in which each volume pixel (voxel) corresponds to a coordinate in (x, y, E).

Although this process is conceptually quite simple, the technique employed to produce those images rapidly, efficiently and with great quality is not as straightforward. The hyperspectral measurement process will be explained in the next sub-sections.

Alternatively the HIPLM system installed in the Laboratory for quantum semiconductors and photon-based bionanotechnology (QS-Group) possesses a second imaging mode of operation. In the normal mode of imaging, the images recorded by the camera are direct images of the sample, which corresponds to a XY image. The second imaging mode, called Conjugate-space imaging, modifies the light's path inside the HIPLM system and allows the camera to observe the angular distribution of the light emitted by the inspected elements, a $k_x k_y$ image instead of a XY image. This imaging mode is discussed in last sub-section of this introduction.

Hyperspectral Imaging

An hyperspectral image is a collection of greyscale 2D images, where each image expresses the intensity distribution of a specific wavelength. Instead of taking one intensity image for the whole spectrum (as a normal camera would), each image is first sent through a special spectrometer, in order to separate its energy (wavelengths) components. The result is similar to a Red, Green, Blue (RGB) image, but with the complete spectrum of probed light instead of only three components. The RGB separation is illustrated below in figure 1.

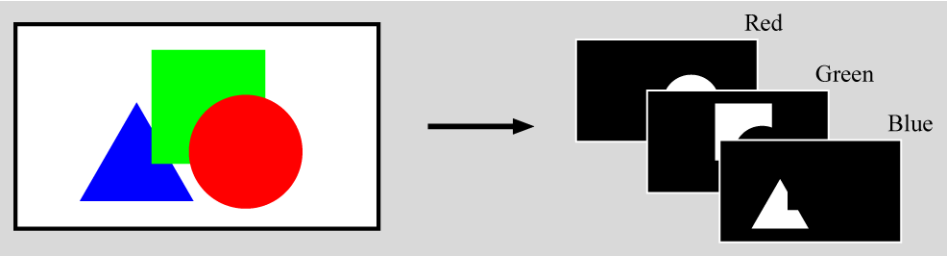


Figure 1 - RGB color scheme - Conceptual color separation within a full color image. Each color is represented with an intensity image, where the white color represents a full intensity, and a black color represent a total absence of the color at that position. Computer uses only three specific colors to represent the commonly used visible color spectrum, but as light is a continuous spectrum, it can be measured and stored much more precisely in an hyperspectral image.

The precise optical concepts of the spectrometer and how it works are out of the scope of this document, but it is necessary to describe what they output. The output image of the spectrometer has

the same morphology as the input one, which means that there is a direct correspondence between the input and output pixels. That said, the snapshots produced by the system during the measurements are not an intensity image at a specific wavelength (as illustrated in the left part of figure 2), but a continuous image in wavelength along the x-axis (figure 2, right part).

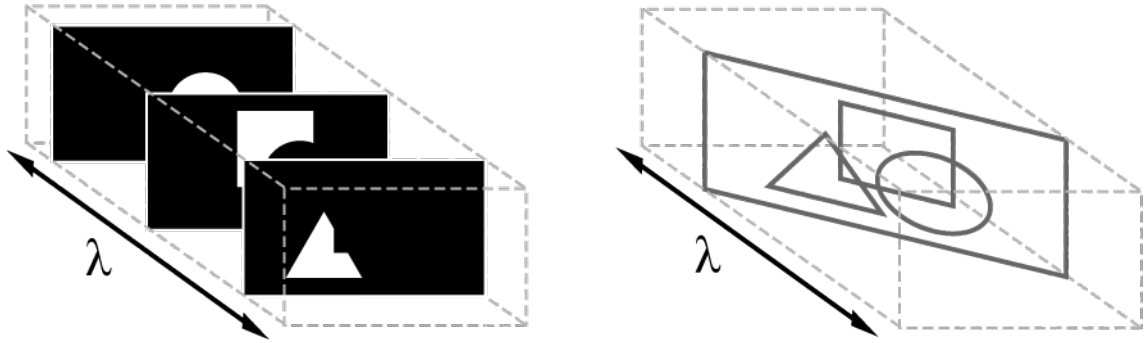


Figure 2 - Hyperspectral imaging - The left part illustrate the final output of the HIPLM system, consisting of a sequence of images, where each image represent the intensity distribution of the light at that specific wavelength. The right part illustrates the snapshot taken by the HIPLM system at a specific central wavelength, before post-processing into the final hyperspectral image. The snapshots are called "unrectified" images, since the x-axis is multiplexed with its wavelength content.

Conjugate-Space Imaging

For the readers unfamiliar with the Fourier transform and its application in optics, the concept could by simplified by stating that instead of observing the spatial disposition of the objects in the image, this secondary mode of operation observes at which angle the light is reflected/emitted/scattered by all the object in the image. The polar and azimuthal angles of scattering are therefore mapped as a function of energy. This mode of operation is therefore quite practical for the direct measurements of the dispersion relation of any light. The schematic in figure 3 illustrates this concept.

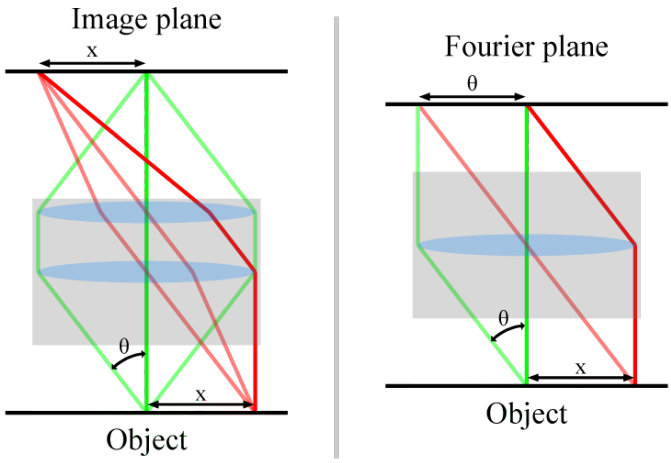


Figure 3 – Schematics of Conjugate-space Imaging - All the light emitted from a specific point on the object will collect to an image point in the real imaging (left), whereas all the light emitted from a specific **angle** from all parts of the object will collect at a specific position in the Fourier plane (right).

User Manual – Common Tasks

Step 1 – General Start-up Procedure

All the procedures of this guide consider that the user is comfortable with the usage of the related software, but mostly the PHySpec software, as it is necessary in the sample's alignment. If not, see Appendix 1 for basic details of operation , consult the respective software manual for further details or ask the laboratory manager.

- Log-in the system and inscribe details in the logbook
- Check the workstation for anomalies (abandoned liquids / samples). If required:
    - Safely dispose and clean the workstation
    - Make note the anomalies in the logbook
    - Email the lab manager regarding the anomaly
- Check that all the equipment is correctly powered on
    - Keithley voltmeter
    - SC-10 Shutter control (shutter **closed**)
    - Power bar of the hyperspectral imager and Apogee camera (identified)
    - Laser(s) (if required), at the appropriate power. Follow the laboratory laser safety procedures at all times.
    - White light lamp intensity(if required)

Step 2 – Procedure for Spatial Imaging

1 – Sample Alignment and Focus

- Put on clean nitrile gloves
- Place the sample on the stage, under the microscope objective
- Open PHySpec, initialize the system and load the latest calibration files
- Open the white light lamp up to an appropriate intensity (up to half the maximum is good)
- Set the HI to 760nm if imaging in the NIR; 760nm is an appropriate wavelength to be able to simultaneously see a large portion of the image with the white light.
- Adjust if imaging in the VIS.
- Start the "Video mode" of the camera to about 1 sec exposure (gives a good trade-off between FPS and brightness for most QW samples).
- Roughly adjust the focus to allow the observation of features on the sample or sample holder
- Move the sample with the XYθ stage until it is completely visible in the image display (or appropriately positioned for the experiment)
- Adjust finely the focus using the Z-stage to obtain the sharpest image possible of the sample's surface
- Stop the "Video mode" of the camera
- Turn off the white light lamp

2 – Optimal parameters evaluation

- Align sample and adjust focus (described previously)
- Before proceeding with the hyperspectral image acquisition, it is important to set-up the following parameters:
    - Camera binning
    - Set the camera resolution to 16bits
    - [*Optional*] Camera temperature control: should not be set to below 2°C for extended period. Lower values will causes condensation and formation of ice crystals on the camera front glass.
- Determine the appropriate acquisition time
    - Move the HI grating to the sample's emission wavelength, and manually open the laser shutter
    - Adjust the laser power to the wanted value, if not already selected.
    - Select the "Manual" acquisition mode and produce a single image exposure
    - Adjust the acquisition time and repeat exposure to obtain the highest intensity without producing image saturation (use the cursor tool to check the intensity of the bright zones). Saturation occurs at a value of about 2^{16}, or 65535. The higher the average intensity of your image, the better signal-to-noise ratio you will get. The noise floor is dependant of the camera temperature, but it lies around 1200-1400 intensity unit, with a typical variance of about 150.
    - Close the laser shutter
- Once your acquisition time is determined, acquire a dark image measurement. This single image is used to get the average background noise of the CCD.
    - Select the "Dark" acquisition mode
    - Adjust the exposure time (identical to the final measurements)
    - Select the number of images to acquire in order to obtain the camera thermal background noise profile (the images will be averaged). Usually, the shorter the exposure, the higher this number will be. Below a 5 sec exposure, we suggest at least 11 to 21 images. At longer exposure, reduction to about 3-5 is tolerable.
    - Save the Dark Image (In the image display, select "File > Save Image")

3A – Single Measurement – PHySpec

- Align sample and adjust focus (described previously)
- Evaluate optimal acquisition parameters (described previously)
- Load the latest calibrations files (if not done previously)
- Proceed with your sample acquisition
    - Select the "Automatic" acquisition mode
    - Setup the desired acquisition wavelength range and step size between images
    - Setup the acquisition time
    - Specify the cube name and description details
    - Open the laser shutter
    - Start the acquisition

    - Upon completion of the acquisition, close the shutter
- Export data
    - Right-click on the cube name and rectify the cube
    - Right-click on the cube to get a preview of the rectified cube in PHySpec
    - [Optional] Export the RAW data (File > Export Cube...)
    - Export the Rectified data (same window)
    - Save the Dark Image (Open the dark image display > File > Save Image)
- [Optional] Post-processing steps
    - Refer to the PHySpec user manual for the post-processing capabilities of the software

3B – Multiple hyperspectral measurements – LabView program

- Align sample and adjust focus (described previously)
- Evaluate optimal acquisition parameters (described previously)
- Close PHySpec
- Open the LabView program
- Load the latest calibrations files (if not done previously)
- Setup the acquisition parameters in the Acquisition Window
- Specify the output folder
- Start the acquisition

3C – Real-Time hyperspectral snapshots – Matlab program

- Align sample and adjust focus (described previously)
- Evaluate optimal acquisition parameters (described previously)
- Before closing PHySpec, setup the HI wavelength to the desired central wavelength
- Close PHySpec.
- Open the Matlab program
- Setup your acquisition parameters
- Start the acquisition

Step 3 – General Closing procedure

- Put on clean nitrile gloves
- Remove all samples and liquids from the HIPLM stage
- Make sure to properly clean all spills
- Check the workstation for samples or garbage and make sure to dispose of your tools, samples and liquids and to clean the workstation for the next user.
- Close ALL the box doors correctly
- Check that all the fragile equipment is correctly powered off
    - Laser(s)
    - White light lamp
    - Peristaltic pump
    - Laser shutter is on the closed state or turned off
- Log-off the system and inscribe details in the logbook

Alternative Step 2 – Procedure for Conjugate Imaging

As mentioned in the introduction, the HIPLM system allows for the imaging of the conjugate (Fourier) space of an image, thus allowing the direct observation of the angular emissions of a sample. The procedure to do so is as follow, and supersedes or adds to the previously defined "Step 2 – Procedure for Spatial Imaging". The following procedure is a guideline only, and you should ***consult the laboratory manager prior to engaging in any conjugate imaging experiments.*** Refer to the Imaging module schematics for more information.

1 – Sample Alignment and Focus

The sample alignment and focus steps are exactly identical to the procedure described in the spatial imaging section. As the conjugate imaging is non-trivial, alignment and focus in the conjugate space is a challenge at best, so those steps are done in the real space before switching to the Fourier space.

Added – Imaging Mode Switch

After the sample is aligned, the trained HIPLM operator will switch the system from the Spatial imaging mode to the Angular imaging mode. Consult the "Switching the Imaging Mode from Real to Fourier Space" section.

2, 3A-3C – Parameters evaluation and Image acquisition

Once the switch in operation mode is completed, from this point on the procedure of parameters' adjustment and image acquisition is identical to the previous section ("Step 2 – Procedure for Spatial Imaging", subsection 2, 3A, 3B and 3C). Conceptually, the image acquisition procedure stays the same, even if the image in itself was modified by a switch to the optical light path.

Details – Switching the Imaging Mode from Real to Fourier Space

The following steps should be done by trained personnel only, as the kinetic mirror is located in the midst of very sensitive optical elements. Touching any of those elements may misalign the whole system or produce visual artefacts in the output image.

Those steps are written here as a reference. ***EXTREME CARE*** is required.

- Put on clean nitrile gloves and make sure to button your lab coat's sleeves.
- Open the side-door of the HIPLM box, giving access to the homogenization stage and the mirror floor
- With the permission of the lab manager, slide the right hand OVER the imaging mirror (blue arrow in schematics) until the index or major finger touches the TOP of the kinematic mirror (red arrow in schematics).
- While holding the mirror mount, FLIP DOWN the kinematic mirror (red arrow) to go from Real-Space imaging to Conjugate-Space imaging (flip up the mirror to come back to Real-Space imaging).
    - The kinematic mirror is spring-actuated. DO NOT let the mirror go freely. Use the hand to accompany the mirror all the way down or up, while twisting the wrist around the imaging mirror (blue arrow).

    - Take extreme care to NOT touch the imaging mirror (blue arrow). Any dust, scratch or irregularity WILL BE imaged directly by the camera, thus greatly degrading the output image quality.
- Remove the hand from the system while avoiding the imaging mirror (blue arrow)
- Carefully close the side door of the HIPLM box, making sure there is no gap left

User Manual – Advanced Details

Software Usage and Troubleshooting

PHySpec (v.1.15.1)

- Make sure the HI was correctly initialized (distinctive noise and status message in the application)
- Make sure the camera was added to the software (under the menu: Camera > Add Camera ; selecting the Apogee driver should identify the camera to add or display "Already Added")
- Make sure the latest calibration files are loaded.
- Consult the PHySpec software manual for its specific usage.

LabView Multi-Acquisition

- All the required equipments are initialized automatically. You should hear the HI system initializes (buzzing sound of a stage moving to its *extrema* 3 times) and hear the Keithley voltmeter initializes to its pre-recorded default configuration (with two loud beeps).
- If no error were displayed, the system should be ready to go.
- Consult the LabView software manual for its specific usage.

Matlab Real-Time Pseudo-Imaging

- The scripts automatically initialize and load the required equipments. If no errors were displayed on the command prompt and asks the user to proceed, the program is ready to work.
- Consult the Matlab scripts documentation for its specific usage.

Troubleshooting

Those steps describe ways to reinitialize the system to a known and working condition, in the case a software problem arises. They should be done IN THE SPECIFIED ORDER, as the risk of damaging or misaligning the system increases with each step.

- If the HI imager, the camera, the shutter control or the Voltmeter did not add correctly, verify that the equipment is correctly powered on; try to restart the application.
- If the problem persists, try to reboot the computer. The communication ports may get stuck, and a reboot will clear the system's ports
- If the problem persists, try to power-cycle the hardware. If accessible, use the power button or the power key. If the power button is not accessible (for the HI and camera), use the switch on the power bar to cut down the power for about 15 seconds before activating it again (be sure to

choose power bar dedicated to those equipments). As the camera and the HI are sensitive equipment, they should never be powered down while executing a task.

- If the problem persists (for the HI), ask the designated lab technician to do a power-cycle of the HI using the switch inside the box. DO NOT ATTEMPT this yourself. The switch is located close to optical components; touching them may misalign the system.

Operating Mode Switch (PL, EL and Fluo)

The HIPLM can be used for multiple applications. Those applications consist primarily in PL (photoluminescence), EL (electroluminescence) and Fluo (fluorescence). In order to increase the quality of the measurements, it is possible to fine-tune the utilized optical components to collect more light or filter undesired light. The two main optical components to change are the beam splitter and the collection optical filters (located after the microscope turret and the beam splitter).

Since changing between those operating modes requires modifying optical components, alignment of the beam splitter and a spectral calibration are necessary after each modification. Refer to the schematics of the Microscope tower for more information.

If necessary:

- Change beam splitter in cage cube (red arrow): Hot/cold mirror, beam splitters, etc.
- Change Optical filters (blue arrow): Laser filters, thermal noise filters, VIS/NIR filters, etc.

Routine Alignment Procedure

Those procedures are destined to the trained personnel in charge of maintaining the HIPLM system. They should not be attempted by an untrained user.

Spectral Calibration

The following procedure describes the way to do a spectral calibration and its related calibration files. Those are necessary for yielding acceptable precision in the measurement and rectification process of the hyperspectral images.

- Remove the goniometer from the XYθ stage
- Make sure the laser shutter is closed
- Put on clean nitrile gloves
- Carefully remove the optical filters, located after the microscope turret and the beam-splitter
- On the XY stage, install the calibration lamp (Neon lamp), using the provided optical post and screw, right below the microscope objective (preferably 10x)
- Over the lamp, insert the diffuser and the small sheet of white paper (for better diffusion)
- The Z-adjustment should bring the white paper sheet quite close to the microscope objective (not more than 5mm to 1cm away), out of focus of the objective (again for diffusion purpose).
- Turn on the neon lamp
- Open PHySpec
- Start the calibration sequence for both gratings, using a 10 sec acquisition time and the default settings for CCD and pixel size (see PHySpec software manual for details)

    - Using a dielectric hot-mirror as a beam-splitter may cause intensity variations in the Neon peaks. Those variations may confuse the calibration algorithm. Be sure to use the adequate reference calibration file, associated to the installed beam-splitter/mirror
- Verify the calibration by moving the HI to spectral lines and verifying that the image at that point is centered on the line. Suggested lines:
    - VIS grating line A: 585.249nm
    - VIS grating line B: 724.25nm
    - IR grating line A: 743.89nm
    - IR grating line B: 885.09nm
- Export the calibration files to the latest calibration folder (*c:\HIPLM\Latest Calibrations*)
- Turn off the Neon lamp and remove it from the XY-stage
- Carefully reinstall the optical filters (if required by the operating mode)
- Reinstall the goniometer on the XYθ stage.

Angular Alignment

Changing the beam-splitter requires a simple realignment of the system, in order to have the microscope objective image projected appropriately on the CCD.

- Put on clean nitrile gloves
- Turn on the white light lamp and place a white paper sample on the stage
- Do a rough positioning and focus of the paper sample (at 760nm, for example)
- Switch the system's imaging mode to Conjugate Space (easier to align)
- Using an appropriate Hex key, loosen the four screws of the beam-splitter cap, but do not remove them completely (loosen by about half a turn to a turn)
- Using your hand, turn the beam-splitter cap about 1/8 of a turn (45°) in either direction. This should bring the cap to a position where it will be possible to remove it by sliding it out
- Slide out the beam-splitter cap and its attached beam-splitter/mirror. Be careful to have a linear lateral movement (perpendicular to the cap) to prevent the optical component to touch the side of the beam-splitter box
- Take the new beam-splitter cap and new optical component (mirror or beam-splitter) and insert them in the beam-splitter box, preventing the optics to touch the box's sides
- Rotate the cap assembly of about 45 degree until the image is back within the CCD field of view (using the "Video Mode")
- Carefully align the white visible circle within the frame of the image. The center of the circle should coincide as much as possible with the center of the image.
    - To align vertically, only carefully rotate the cap assembly within the beam-splitter box socket. Slight movement will have a amplified effects, so a minute manipulation is required.
    - To align horizontally, you will have to pull out the assembly and adjust the mirror's inclination in relation to the beam-splitter cap. Great care must be taken so that the surface of the mirror coincides with the center of the beam-splitter cap, so that the

projected image is centered on the optical axis before but also after the beam-splitter assembly.

- Once adequately aligned, hold the cap in place with one hand while you tighten back the screws to fix the cap assembly back in place.
- Verify that the alignment is still adequate after tightening the screw. Correct if necessary
- Close the while light lamp and remove the white paper sample
- Switch the system back to the Real-Space imaging mode
- Proceed with a full spectral calibration (mandatory)

Detailed description

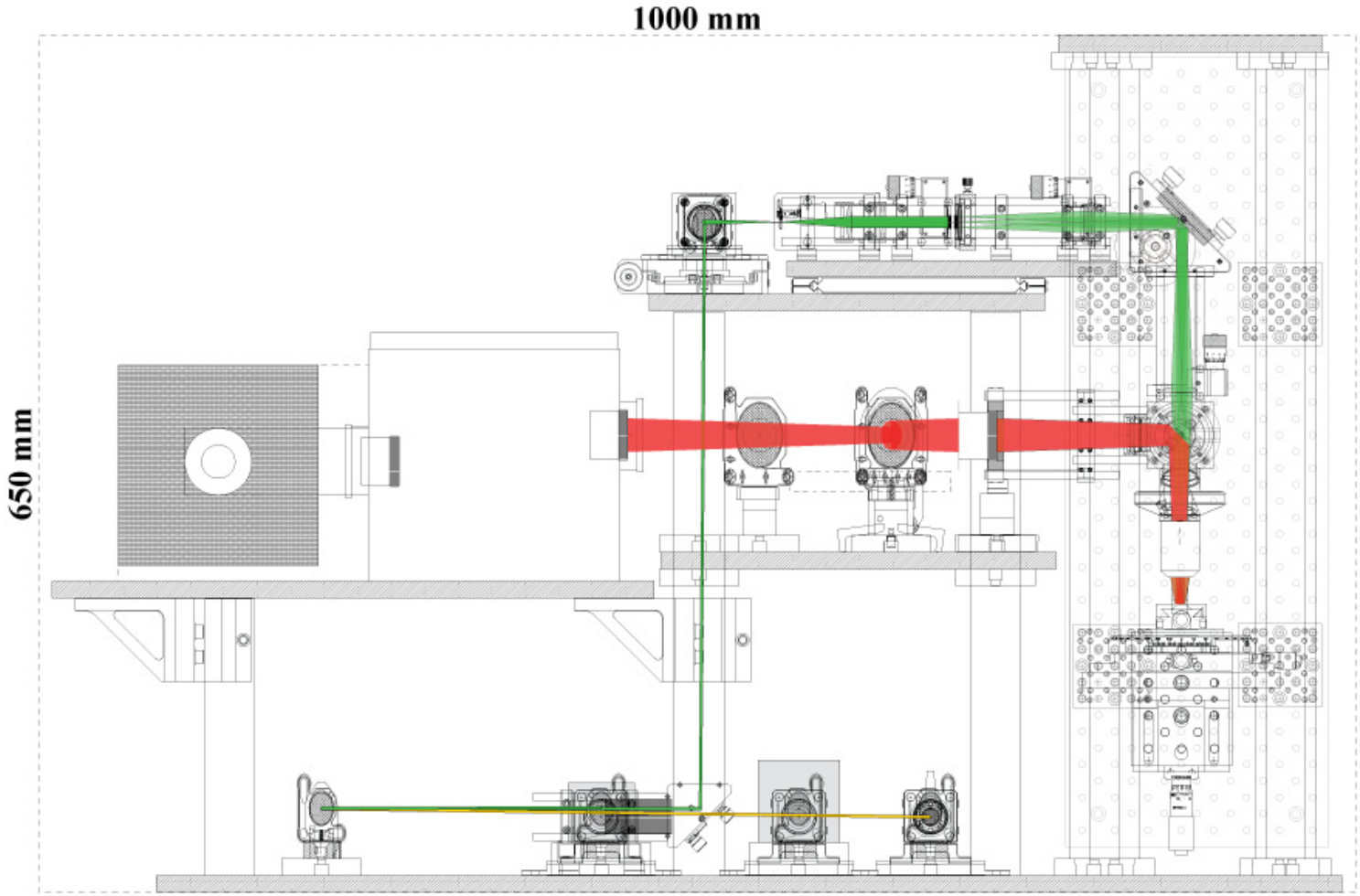
Overview

Description

Due to its multipurpose applications, the HIPLM system is composed of several modules which can be adjusted independently. Each of those modules is to be aligned on their own and between themselves if the system falls out of alignment.

The system is divided into five modules: First the Laser floor, where all the light sources are installed. The light pump used for PL or fluorescence is then coupled into the second module, the Beam homogeniser platform. This platform enables a homogeneous illumination of the substrates over the field of view. It is also possible to switch the illumination to a single hot spot on this floor. The Microscope tower is the third section, where most of the collection and injection optics is installed along with interchangeable filters. The lower section of the Microscope tower is only sector that should be accessible to the unspecialized HIPLM users. The collected PL or EL from this tower is then sent to the Imaging module, where the advanced user can switch to the conjugate space imaging for SPR studies. The last module consists of the Hyperspectral box containing the Volume Bragg Grating from Photonetc Inc and the Apogee Camera. Each module will be discussed in more details in the coming sections.

Schematics



Laser floor

Description

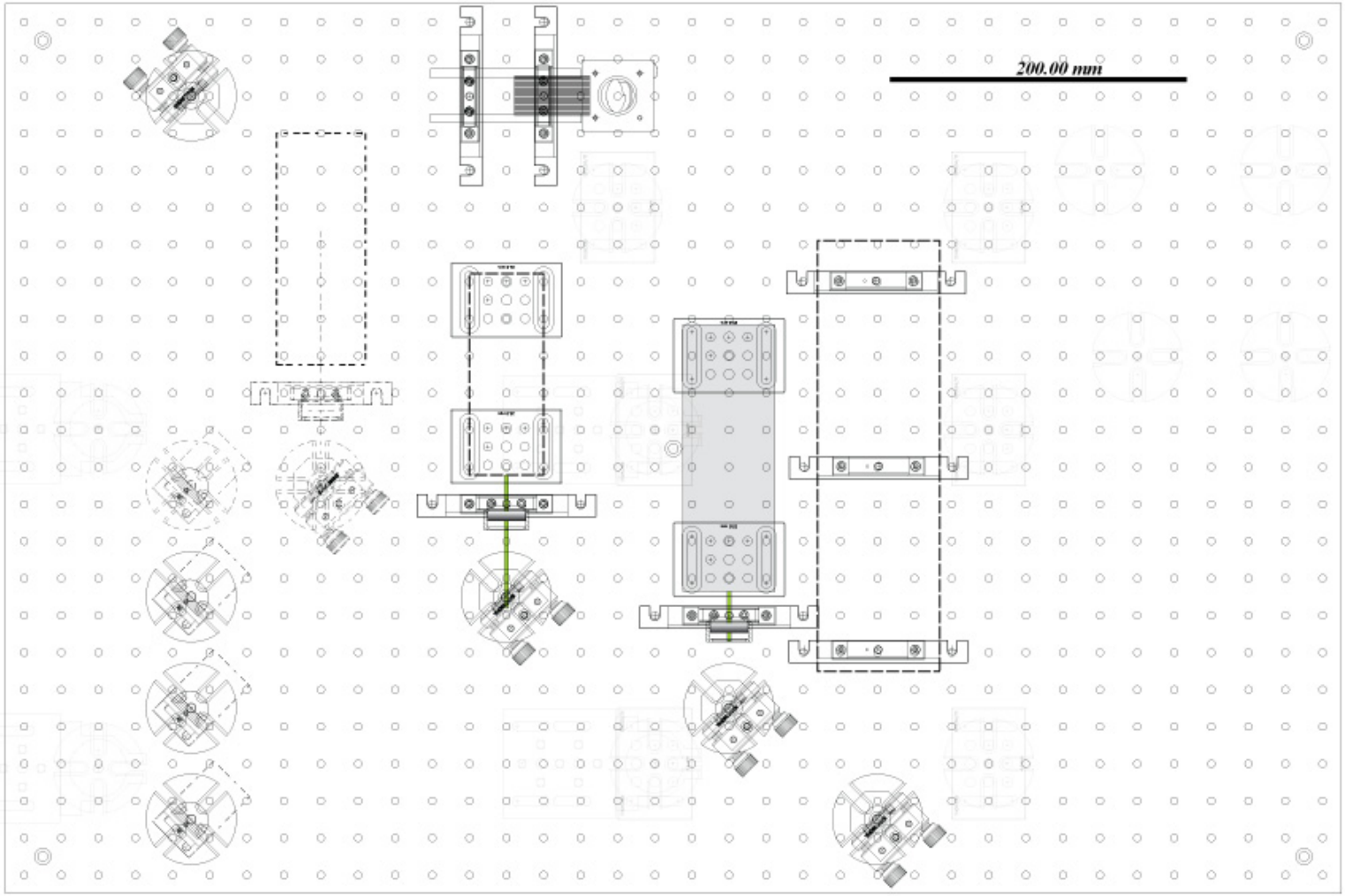
The laser floor is designed to support four (4) different illumination sources, which can be employed as various PL pumps or fluorescence. Each source is coupled to a pair of mirrors mounted on a standard and kinetic (flipper) mounts. Those are employed to align independently each source with the last two mirrors of the laser floor. These last two mirrors are aligned with the rest of the system and should NOT be disturbed when installing a new source. All the sources are finally coupled into a multimode optical fibre (not shown) and led to the Beam Homogenizer.

To switch between light sources to another, open the side of the environmental box and select the kinetic mirror corresponding to the desired light source.

List of parts

Description	Supplier		Part No.		QTY
Flipper mount	Newfocus		9891M-L		3
Thread adapter	Thorlabs		AP6M4M		3
Height spacer	Thorlabs		BA2S7/M		4
Mirror	Thorlabs		BB1-E02		8
Height spacer	Thorlabs		CLCPB1/M		4
Cage plate	Thorlabs		CP08/M		4
Cage rod	Thorlabs		ER6		4
Laser filter	Thorlabs		FL532-10		2
Mirror mount	Thorlabs		KCB1		1
Mirror mount	Thorlabs		KS1		4
Mounting base	Thorlabs		LCPB1/M		4
Post mounting	Thorlabs		MA4/M		4
Breadboard	Thorlabs		MB6090/M		1
Mounting base	Thorlabs		PB2/M		7
Lens tube	Thorlabs		SM1L05		2
Lens tube	Thorlabs		SM1T20		1
DPSS Laser 1	Viasho		VA-II-N-532		1

Schematics



Beam homogeniser platform

Description

The beam homogeniser is a complex module designed to generate a uniform illumination at the field of view of any microscope objective and thus, independently of the laser source. The functioning is illustrated in the "Principle of beam homogenization" subsection and goes roughly as follows:

A) A laser source is coupled into the multimode fibre. Most lasers have a pseudo-Gaussian spatial distribution I(x) and a sharp angular/wavevector distribution in I(k). The phase of laser beam $\varphi(x,k)$ is almost unique (coherent).

B) After the 5m of the multimode fibre, independently of the input, the spatial distribution I(x) is a Gaussian defined by the fibre coupler. However, speckle pollutes the distribution, as natural coherent interferences statistically occur. The wavevectors of the light are cleaned and is virtually collimated, due to the fibre size and the collimation system. The phase $\varphi(x,k)$ is now randomized.

C) The rotating diffuser is placed after a lens where the wavevectors are broadened. Following the rotating diffuser, the spatial distribution is still the same, but the wavevector distribution is broadened and the speckles time averaged (60hz).

D) A kaleidoscope is place at the focal point of a secondary lens, which projects a time smoothed spatial Gaussian at the kaleidoscope input. The time-independent speckle is now in the wavevector space.

E) At the kaleidoscope output, a spatially distributed flat-top (2%) illumination is present. The phase $\varphi(x,k)$ is further randomized. The time-independent speckle effect is distributed between the two planes (spatial I(x) and conjugate I(k)) and minimized by the time-average.

F) A collection optics resizes the beam and projects the appropriate object at the back focal plane of the microscope objective. A flat-top (2%) can then be projected at the objective's field of view.

The translation stage can be moved to take the rotating diffuser and the focusing lenses out of the optical path. This will result in a focusing of the light source into a hot spot on the sample. This can be employed for laser surface modifications or for alignment purposes.

List of parts

General:

Description	Supplier		Part No.		QTY
Rotating diffuser	SUSS		60-1105-911-000		1
Acromat lens	Tholabs		AC254-075-A		1
Acromat lens	Tholabs		AC254-100-A		1
Thread adapter	Tholabs		AP25E6M		4
Thread adapter	Tholabs		AP4M3M		2
Thread adapter	Tholabs		AP6M4M		1
Mirror	Tholabs		BB1-E02		2
Cage plate	Tholabs		CP08/M		8
Height spacer	Tholabs		CPB1/M		6
Cage rod	Tholabs		ER1		4

Cage rod	Tholabs		ER10		12
Cage rod	Tholabs		ER12		4
Cage rod	Tholabs		ER4		4
XY lens mount	Tholabs		HPT1		1
Mirror mount	Tholabs		KCB1		2
Kinematic mount	Tholabs		KMCP/M		1
Best form lens	Tholabs		LBF254-050-A		3
Best form lens	Tholabs		LBF254-100-A		1
Translation stage	Tholabs		LT1/M		1
Breadboard	Tholabs		MB2025/M		1
Breadboard	Tholabs		MB3045/M		1
Mounting post	Tholabs		P1		4
Mounting base	Tholabs		PB2/M		1
Post Spacer	Tholabs		PS5/M		1
Mounting base	Tholabs		SCPB1/M		2
Lens tube	Tholabs		SM1T20		1
Lens tube	Tholabs		SM1V05		5
Translation Mount	Tholabs		SM1Z		2
Translation Stage	Tholabs		TBB0606/M		1

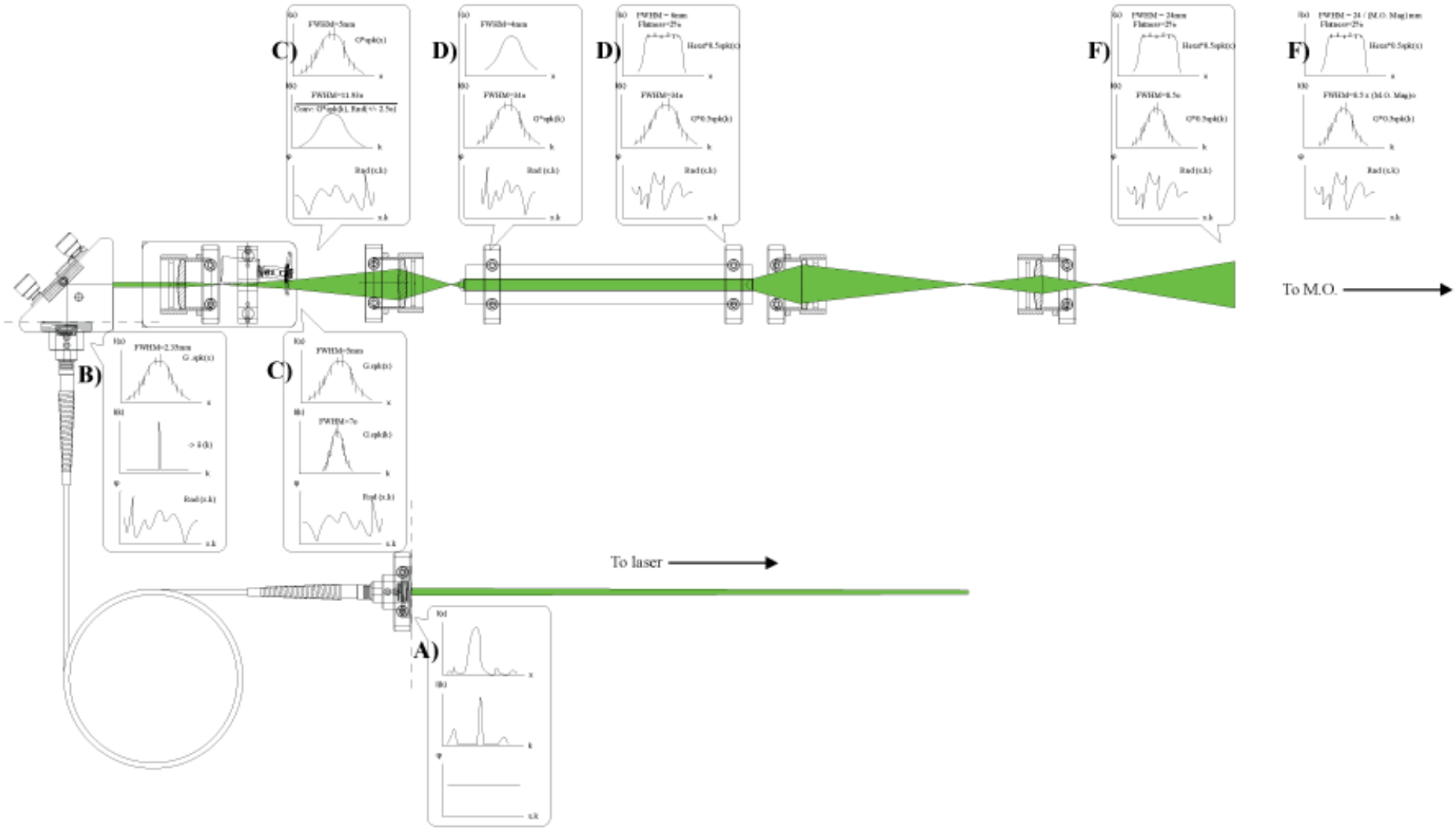
Kaleidoscope:

Description	**Supplier**		**Part No.**		**QTY**
1/2'' Mount post	Thorlabs		PS3		6
Cage Plate	Thorlabs		CP02/M		2
Achromatic Doublet Pair	Thorlabs		MAP1030100-A		1
Aspheric Condenser	Thorlabs		ACL2520-A		2
Breadboard	Thorlabs		MB1015/M		1
Rod mount	Edmund		NT64-915		1
Silica Hex light pipe	Edmund		NT65-835		1

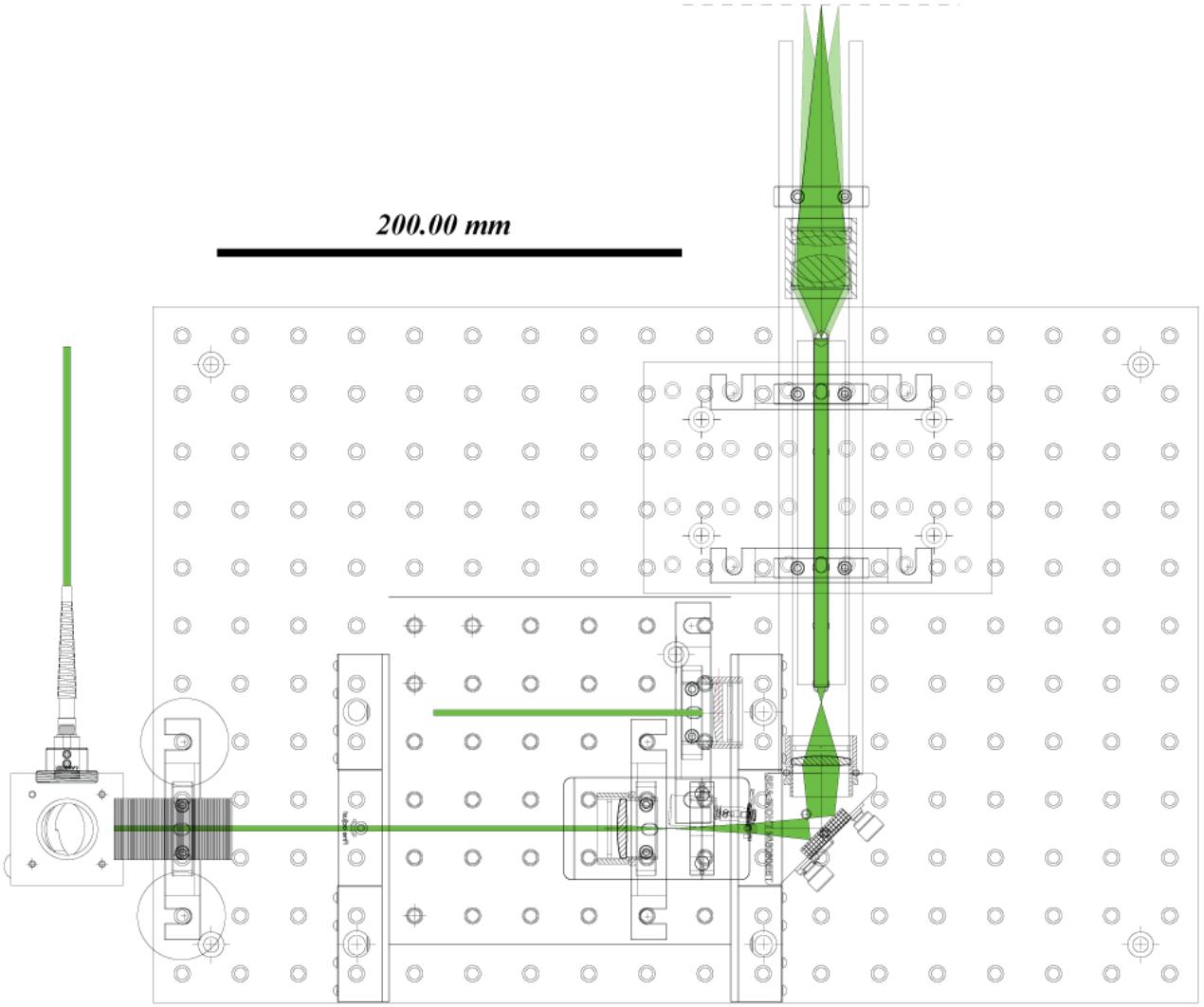
Fibre setup

Description	**Supplier**		**Part No.**		**QTY**
SMA Collimation	Thorlabs		F220SMA-A		2
SM1 Adapter	Thorlabs		AD11F		2
5m Multimode fiber	Thorlabs		M24L05		1

Principle of beam homogenization



Schematics



Microscope tower

Description

The microscope tower is where an important fraction of the HIPLM optics takes place. When using the system for PL, the homogenized light pump comes at the top and passes through a hot mirror (or cold for other uses) located in the cage cube. The pump reaches the microscope objective (MO) in place where the transmitted light is homogeneous at the focal point of the MO. The emitted PL is collected by the MO and reflected by the hot mirror in place. In EL mode, it is recommended to use a silver mirror for a flatter broadband response. Appropriate filters are placed at the exit of the cage cube, such as laser and thermal filters, and are indicated by the blue arrow in the schematics. The PL signal is then sent to the Imaging module.

Common users have access to the lower section of the Microscope tower through two doors placed in the environmental box. Users can change the MO by rotating the objective turret and position their samples in XYZ$\theta\phi$, i.e. the 3 spatial axis, polar and azimuthal angles. Not indicated in these schematics are the tubes coming in and out of the peristaltic pump, located outside the environmental box. Various tubes reach the sample holder and are used to control injection of liquids.

Also, note that operating a mode switch (EL, PL, Fluo) or basic angular alignment of the system might involve a change in beam-splitter (see Operating Mode Switch or Routine Alignment Procedure sections). This filter is located in the cage cube, indicated by a red arrow in the schematics. Follow the procedures described in the previous sections if this is necessary.

List of parts

General:

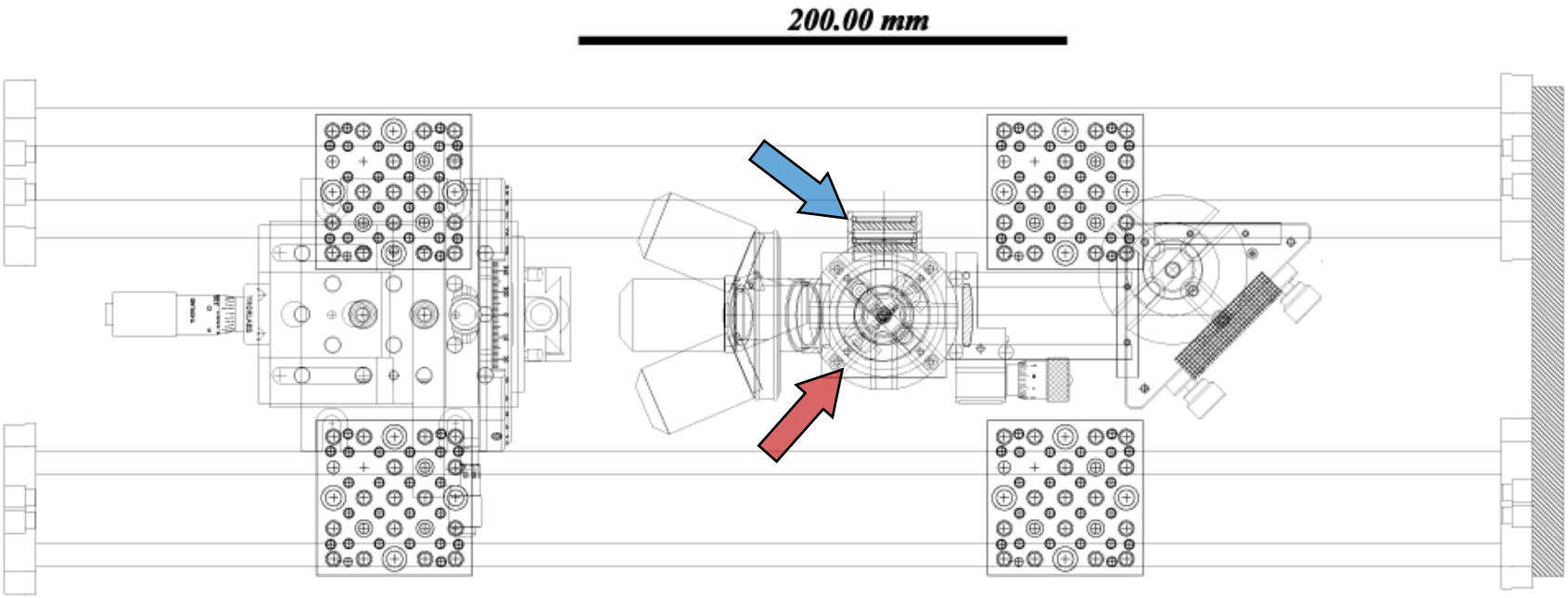
Description	Supplier		Part No.		QTY
Cover plate	Thorlabs		B1C		1
Rotatable platform	Thorlabs		B3C		1
Mirror	Thorlabs		BB2-E02		1
Cage cube	Thorlabs		C4W		1
Cage adapter	Thorlabs		CP07T		2
Cage rod	Thorlabs		ER4		4
Filter mount	Thorlabs		FFM1		1
Mirror mount	Thorlabs		KCB2		1
Best form lens	Thorlabs		LBF254-100-A		1
Shorpass filter	Edmund		NT47-590		1
M.O. 10x	Edmund		NT58-516		0
Hot mirror	Edmund		NT64-469		1
Long pass	Edmund		NT64-513		1
Objective turret	Thorlabs		OT1		1
Mounting post	Thorlabs		P30/M		2
Mounting base	Thorlabs		PB2/M		4
Post spacer	Thorlabs		PS3		1

Base plate	Thorlabs		PT101		1
Thread adapter	Thorlabs		RMSA2		4
Lens tube	Thorlabs		SM1L03		3
Translation Mount	Thorlabs		SM1Z		1

Stage:

Description	**Supplier**		**Part No.**		**QTY**
Angle plate	Thorlabs		AP90/M		1
Goniometer	Thorlabs		GNL10/M		1
Breadboard	Thorlabs		MB1515/M		1
Translation stage	Thorlabs		PT1/M		1
Linear&Rotation stage	Thorlabs		XYR1/M		1

Schematics



Imaging module

Description

The imaging module is accessible through the side of the environmental box. This platform is where the imaging plane at the camera is decided between normal imaging, for standard XY mapping , or conjugate imaging, for $k_X k_Y$ mapping. This later mode is employed for the construction of the dispersion relation in $I(E, k_X, k_Y)$ of any light scattered under the MO.

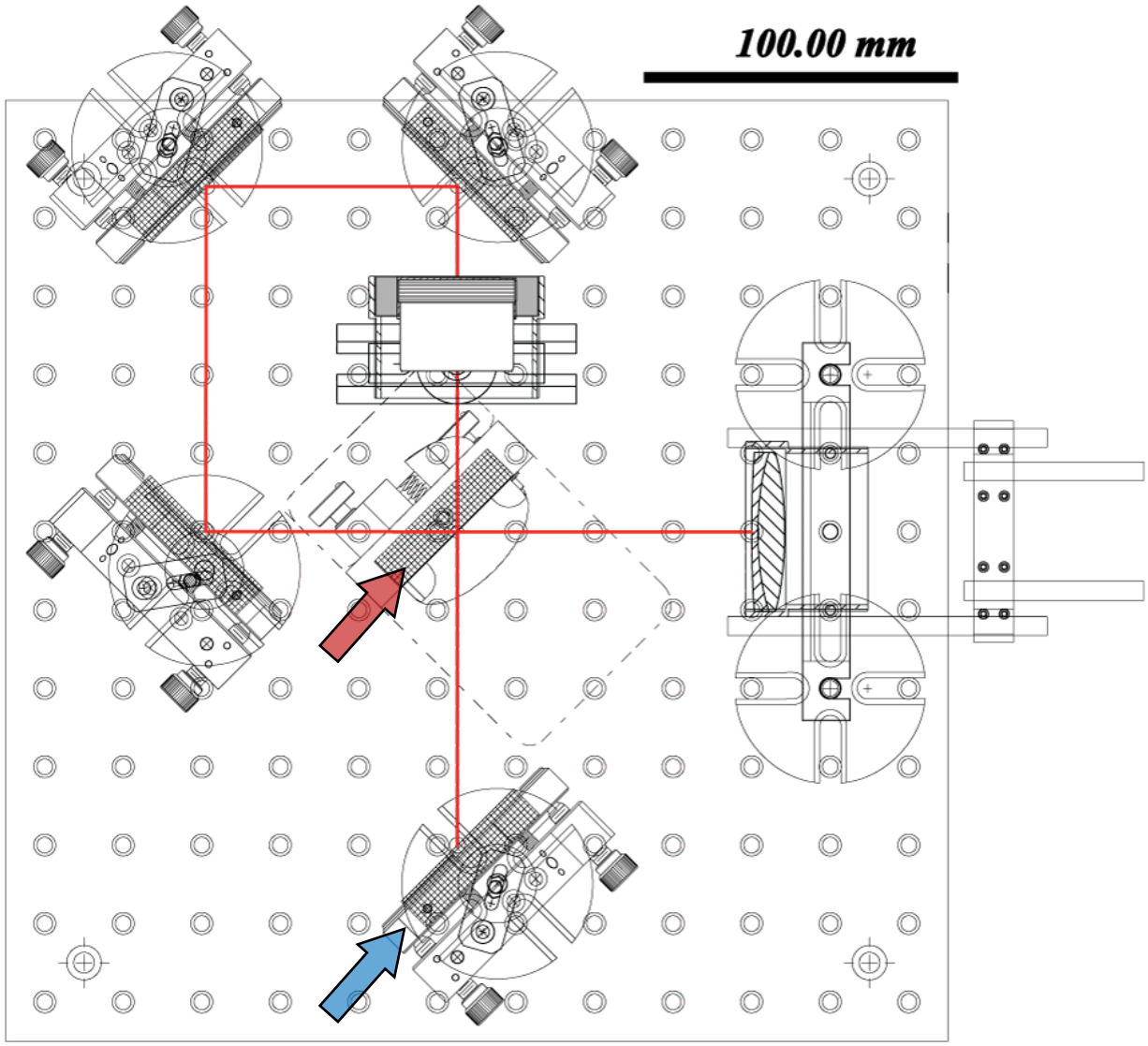
As described in the previous section, there are two critical items in this module. The first one is the imaging mirror, indicated by the blue arrow in the schematics. This mirror is positioned at a focal point of both the normal and conjugate imaging modes: i.e. a real image is visible when placing a lens paper on this mirror. While this is useful for alignments, it is an important source of noise in the measured signal (PL,EL or Fluo): if this mirror is scratched or dusty, it will show in the collected data.

The second important part on this floor is the kinetic mirror, indicated by the red arrow in the schematics. When this mirror is in the erect position, the light is directly sent to the imaging mirror and a XY map is sent to the hyperspectral imager. When the mirror is down, the optical path is elongated as to project the Fourier components of the MO to the imaging mirror. A conjugate space cartography is then sent to the hyperspectral imager. The procedure for conjugate imaging is described in a section above.

List of parts

Description	Supplier		Part No.		QTY
Flipper mount	Newfocus		9892M-L		1
Thread adapter	Tholabs		AP6M4M		1
General clamp	Tholabs		CL5		2
Cage rod	Tholabs		ER3		4
Cage rod	Tholabs		ER4		4
Kinematic mount	Tholabs		KMCP/M		4
Miror mount	Tholabs		KS2		4
Cage plate	Tholabs		LCP01/M		1
Cage adapter	Tholabs		LCP02		1
Mounting base	Tholabs		LCPB1/M		1
Breadboard	Tholabs		MB3030/M		1
Nikon Tube lens	Edmund		NT58-520		1
Mounting base	Tholabs		PB2/M		7
Mirror	Tholabs		PF20-03-P01		5
Post spacer	Tholabs		RS03		4
Post spacer	Tholabs		RS05		4
Post spacer	Tholabs		RS075		7
Tube Lens Adapter	UdeS		Homemade		1

Schematics



Hyperspectral box

Description

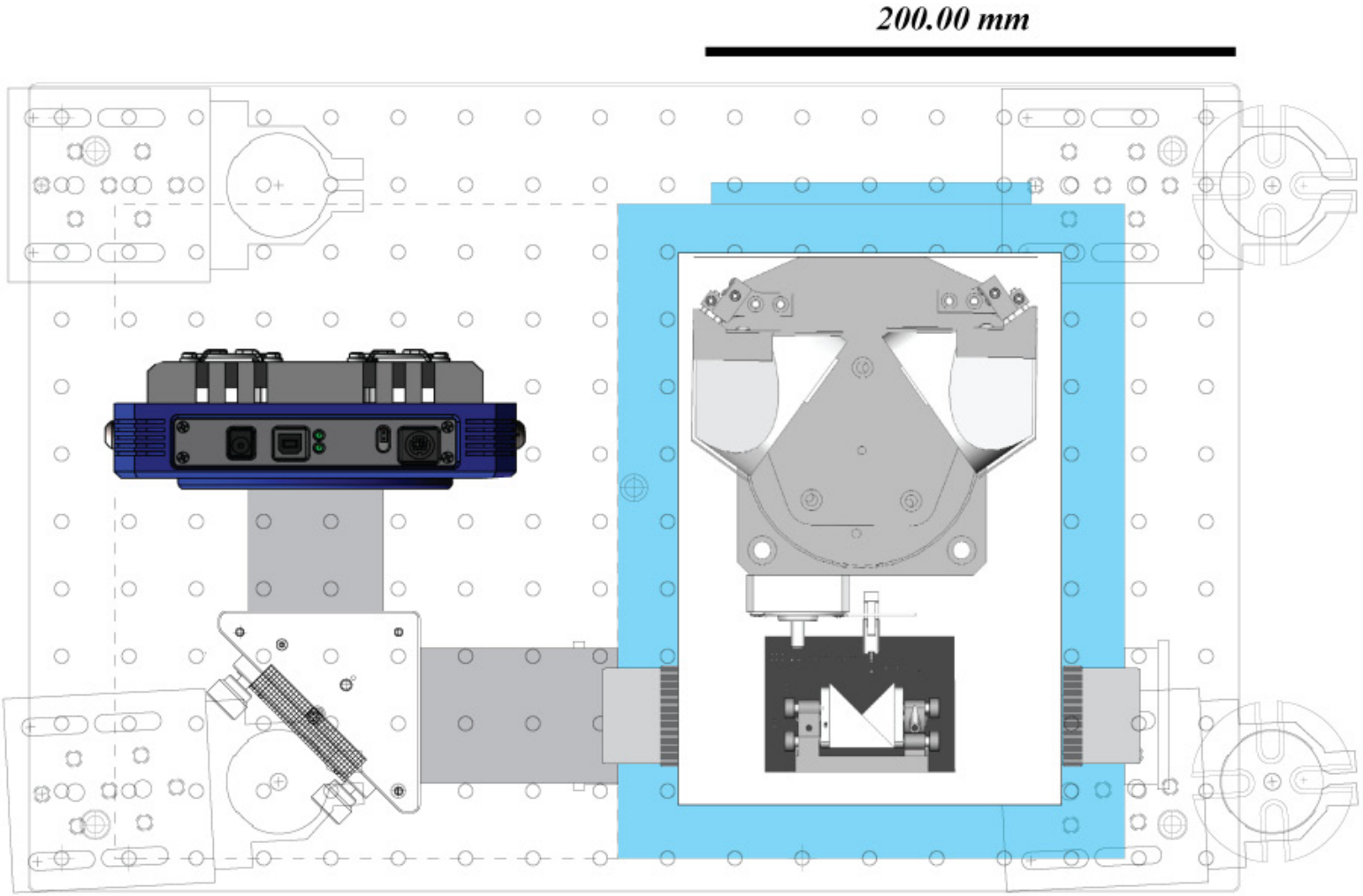
This last module contains Photonetc Inc hyperspectral imager (HI) and the CCD camera. The HI contains two sets of Volume Bragg Gratings (VBG) which are designed to work from 400-740nm (VIS) and 740-1000nm (NIR) respectively. The HI enables the spectral spreading of the image on the camera, while preserving the XY or $k_X k_Y$ dimensions. Hyperspectral cubes are then reconstituted with the various software programs presented in the sections above.

List of parts

Due to Non-Disclosure Agreements with Photonetc Inc, the authors will not specify the system in great detail in this section. However, it is important for the advanced user and lab managers to know about the following:

- Input/Output tube-lenses: Nikon Tube lens (Edmund), part# NT58-520
- Protected silver mirror employed inside the HI
- The camera is an ALTA F32 from Apogee: the technical sheet is available here.

Schematics



Appendix 1 - HIPLM control with PHySpec

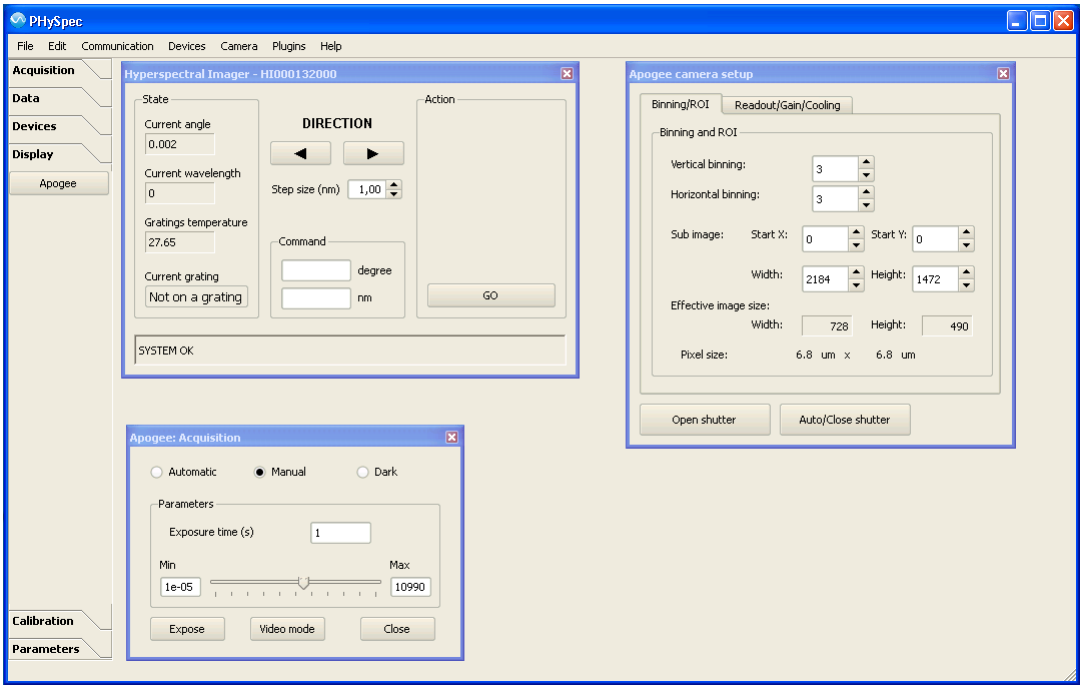


Figure A1.1 - PHySpec interface - Specific sub-windows are opened by selecting the appropriate tabs on the left column and pressing the related button. The HI device control is found under "Devices > HI000132000", the camera parameters under "Parameters > Apogee", and the acquisition window under "Acquisition > Apogee".

Adding the HI device

- Open the communication port (under the menu communication). This should be done automatically when the program opens and it should detect automatically which port to use.
- Open the device list and search for devices (menu "Devices > Devices list..." and button "Search for devices"). Again, this should be done automatically at program startup.

Adding the camera

- Select menu "Camera > Add camera..."
- Select the appropriate driver and camera (in this case, Apogee and Alta U32 respectively).

HI control

- In the Hyperspectral imager control window, input the desired central wavelength and press "GO" to bring the HI grating in the adequate position. The display's central line should be centered at the current wavelength if the calibrations are accurate.

Acquisitions

Manual

- Select the manual acquisition mode in the Apogee acquisition window
- Move the grating to the desired position
- Select the exposure time
- Press "Expose" for a single image, press "Video mode" for a continuous image feed

Automatic

- Select the automatic acquisition mode in the Apogee acquisition window
- Specify the wanted wavelength limits and step for your acquisition
- On the Exposure tab, specify the exposure time for your images
- Input a cube name for the acquisition run
- Press "Start" to launch the acquisition sequence

Cube rectification

Upon completion of an automatic acquisition (a full unrectified cube), it is necessary to rectify it in order to produce a practical hyperspectral image. To do so, right-click on the data button ("Data tab > Cube name") and select rectify.

After rectification, it is important to save your data, by exporting them (menu "File > Export cube...").